Research on the Norton Theorem's Independent Experiment Model Applying the DCAC Lab

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Abstract

This paper explores the application of the Norton Theorem in the DCAC Lab to study the Independent Experiment Model. The conceptual structure of this study is based on the DET10013 Electrical Technology subject. Students in semester 1 are required to take this subject, as it is mandatory for all students in the Electrical Engineering Department (JKE). The lecturer discusses the specifications for performance evaluation, encourages students to engage in self-directed experimentation, and explains the procedures for applying the appropriate instruments and metres. Subsequently, the students autonomously devise the equipment for the experiment and choose them accordingly to meet the required standards. The students participated in practical activities that included measuring actual quantities, constructing their experimental techniques, and they were reporting experimental data, and utilising sophisticated circuit simulation. Additionally, they can build their circuits within the classroom setting and utilise them as components of an experimental model. Experimental proof confirms that using a self-directed experimental teaching method effectively increases students' interest, improves their basic experimental skills, develops their overall experimental aptitude and innovative experimental abilities, and ultimately increases the quality of subsequent related experimental courses.

***Keywords* :** *Norton Theorem, DCAC Lab, Norton Current (IN), Norton Resistance (RN).*

I. INTRODUCTION

Norton's Theorem is a fundamental lesson that should be included in higher engineering institute curriculums. It serves as a foundation for pursuing additional vocational education. The teaching curriculum includes two parts: theory and experimentation. A scientific experiment, also known as a basic experiment, serves a primarily cognitive objective by seeking to enhance our comprehension of reality, without necessarily focusing on its practical application. The objective of a technological experiment is to produce valuable knowledge that can be applied in practical situations [1]. In 1926, Edward Lawry Norton (1898-1983) wrote an internal Bell Laboratory technical report that briefly discussed the merits of using the equivalent circuit's current source form in certain applications, which inspired the name Norton's Theorem [2]. Norton's theorems are widely used in a variety of contexts, ranging from simple tasks such as source modelling networks to complex electrical circuit analysis. According to Norton's theorem, any circuit with multiple power supplies and resistors can be swapped with a circuit with a current source and one resistor in parallel. A Norton equivalent circuit is a simple alternative to any complex bilateral network. It also includes Norton equivalent resistance, Norton equivalent current, and load resistance. Before calculating Norton equivalent resistance, remove all active network sources. However, all sources must be independent. If the network contains dependent source or sources, alternative techniques must be used to determine Norton equivalent resistance. By closing the voltage source and opening the current source, one can disconnect all independent sources within the network. The load resistance is open-circuited when calculating the Norton equivalent resistance. A direct wire (short circuit) connection between the load points is necessary to measure the Norton equivalent current. The resulting current can be determined. [3]. Simulation technology is essential for teaching electrical and electronic engineering. Simulation technology is a significant advancement in science and technology. It utilizes computer technology to analyse system principles and develop models or dynamic experiments. Simulation technology enhances the delivery of electronic and electrical teaching content to students, making it more engaging. Students can easily adjust electronic parameters and gain a deeper understanding of relevant knowledge through participation in the study. This will improve students' understanding of

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more relevant material and their ability to assess relevant issues in different contexts. The effectiveness and learning potential of students have both increased, and people's perceptions of electrical and electronic teaching methods have generally changed. In addition to improving experimental teaching outcomes, simulation technology and operational experimentation can also encourage students' inventiveness and creative thinking. Consequently, when teaching electronic and electrical experiments, a focus should be placed on the integration of simulation technology with operational experiments [4]. Experimental teaching is an essential part of the educational process. Because of its characteristics, the circuit course focuses on confirmatory experiments first, followed by design and thorough experiments. The primary goal of the basic confirmatory experiment is to strengthen students' understanding of theoretical concepts and improve their practical abilities. This includes learning how to use common electronic instruments and equipment, choosing appropriate components, measuring basic physical quantities, and troubleshooting common problems. The design experiment builds on basic experimentation instruction by requiring students to create a plan for the experimental procedure, select appropriate devices and testing instruments based on the design objective, and work independently. Experiments with common unit circuits capable of performing basic functions. The exclusive use of an experimental teaching method severely limits students' cognitive capacity and reduces their motivation and passion for learning the subject. The traditional teaching approach has been transformed by combining years of theoretical and experimental teaching experience and adapting to the demands of today's teaching reform and systems. The experiment box serves as the primary platform, with the experimental circuit standardized and modularized. This allows students to design their own experimental circuits, choose appropriate instruments, and accurately measure physical quantities. The combination of the validating experiment and the design experiment improves students' practical skills and independent learning ability, exemplifying the concept of "scientific, enlightening, and adaptable".

II. LITERATURE REVIEW

Our modern lives rely heavily on electronic equipment. Knowing the electrical current going through each component of a circuit, as well as the related voltage drop, is critical for getting the required function out of the device that uses it. When we get these results, we declare the circuit is solved [5]. Norton's theorem is one of the approaches for finding the solution of a DC circuit. Norton's theorem, also referred to as Mayer's theorem, was formulated concurrently in 1926 by Hans Ferdinand Mayer, a researcher for Siemens & Halske in Germany, and Edward Lawry Norton, an engineer and researcher at the well-known Bell Labs in the United States [6]. One of the most common applications of Norton's theorem is to replace a substantial part of a circuit, which is often complicated and uninteresting, with a very simple equivalent. The new simplified circuit allows us to quickly calculate the voltage, current, and power that the old circuit can give to a load. The Norton theorem allows for the replacement of a complex with an equivalent circuit which is parallel circuits includes with a single current source (IN), parallel resistance (RN), and load resistance (RL). After building the Norton Equivalent Circuit, the load voltage VL or load current IL can be simply calculated. The Norton equivalent, depicted in Figure 1(a) and Figure 1(b) with a single current source and a parallel resistor, can be used to represent any two-terminal network that includes sources and resistances, according to Norton's theorem. Because the original and Norton representations of the network are externally equivalent, switching from the original to the Norton version has no effect on the external currents or voltages at the two terminals [7].

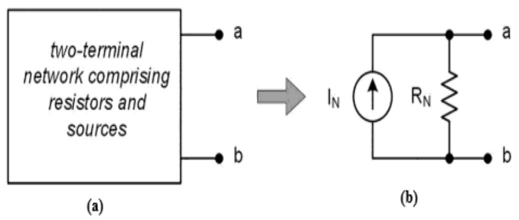

Figure 1 (a): Original Circuit (b): Norton equivalent circuit.

In truth, IN represents the current that flows between terminals A and B when they are bypassed. Similarly, RN represents the corresponding resistance between the original network's terminals A and B after removing the load resistance and replacing all sources with their internal resistances [8].

The approach to finding a solution Norton. The following step is linked to the theorem [9]:

i. Eliminate the Load Resistor (RL)
ii. Find the Norton current (IN) across the break.

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iii. Determine the Norton Resistance (RN) by either shorting the circuit when the voltage source terminal is provided or opening the circuit when the current source is provided.

iv. Transform the circuit into a Norton Equivalent circuit by incorporating RL.

v. Calculate the load current (IL) value.

Thus, after the steps ii and iii, the value of IN and RN have been determined. The Norton Equivalent with inclusion of RL in the circuit will be as shown in Figure 2.

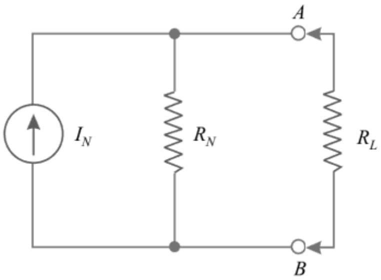

Figure 2: The Norton's Equivalent Circuit [10]

In theory, the IL can be determined with Figure 2 using the formula:

$$IL = I_N \times \left(\frac{R_N}{R_N + R_L}\right) \quad \ldots\ldots\ldots\ldots\ \textbf{Equations 1}$$

III. RESEARCH METHODOLOGY

The process of the teaching method is divided into 3 steps which consist of an Experiment Content Selection, Application of the Pedagogical Approach and Evaluation of Results (Theoretical and Experimental).

A. Experiment Content Selection

Although the circuit theorem experiment serves as a basic course, our electrical speciality begins with the circuit experiment. The use of learning instruments and the competent operation of experiments are of equal importance to students. Their development into competent technicians is facilitated by the application of experimental procedures and methods. It might be difficult to captivate students when teaching them the fundamentals of theoretical design and calculation. Concerns about the study's ability to address real-world problems are more prominent among students. Different topics and teaching pedagogies are frequently developed by educators for the same knowledge point, leading to a range of experimental teaching effects. Ya-ning et al. state that there is a connection between experimental teaching content and teaching objects. Teaching content needs to be tailored to the different levels of students [11]. There are two parts to the experimental content, which are the fundamental component and the enhanced part. These parts are divided into two parts for different teaching levels. At the most fundamental level, students must be able to open the DCAC lab software, construct the selection circuit inside, and understand how to use the application. Students can use the components from the library in Figure 3 during the simulation [12]. Students can use a variety of materials in the experiment.

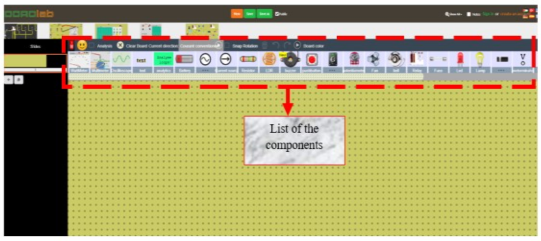

Figure 3: The DCAC Lab's Framework

B. Application of the Pedagogical Approach

During this step, students will receive guidance on how to simulate the Norton Theorem using the DCAC LAB. The students will provide the parameters for configuration. The simulation will provide students with results, including measurements of Norton resistance (RN), Norton current (IN), and load current (IL). Figure 4 illustrates the circuit that students are required to sketch in the DCAC software, which the circuit was using an independent voltage source. The definition of independent voltage source is a voltage that is independent of other components in a circuit and comes from an independent voltage source. One example of an independent source is a 10V voltage source since the voltage stays the same [13].

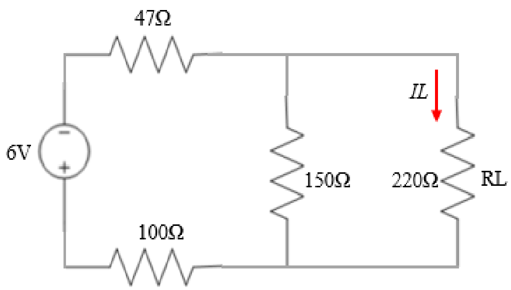

Figure 4: Circuit for Experiment.

Based on Figure 5, the experimental circuit is constructed. From the circuit, students need to set up the value of the DC supply which consists of 150V, 120V and 20V. Besides this, students also need to set up the arrangement of the resistor with the accurate value.

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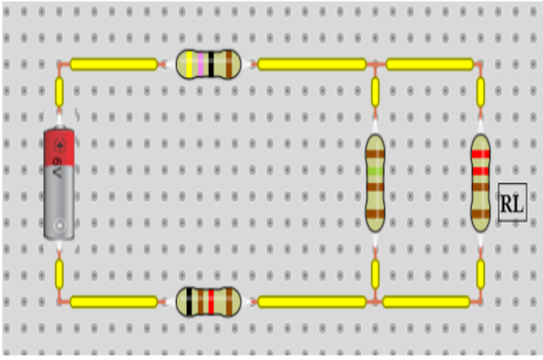


Figure 5: Arrangement of the Circuit by using the DCAC lab.

At this point, students apply the procedure for solving Norton's theorem to this experiment. The first step is to disconnect the RL and use an ammeter to measure the current entering the circuit at the terminal break. You can see the current measurement in Figure 6.

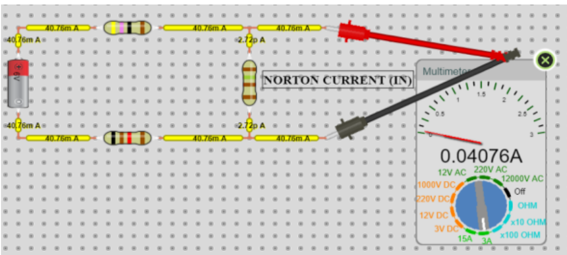


Figure 6: Circuit of the current measuring by using the DCAC lab.

Next, disconnect the power source and short the supply terminal to get the RN reading. To find the source's internal resistance, short-circuit it and then remove the load's resistance cited as [14]. The value of the RN can be measured by using an ohm metre. The procedure for determining the RN at the circuit pin is illustrated in Figure 7.

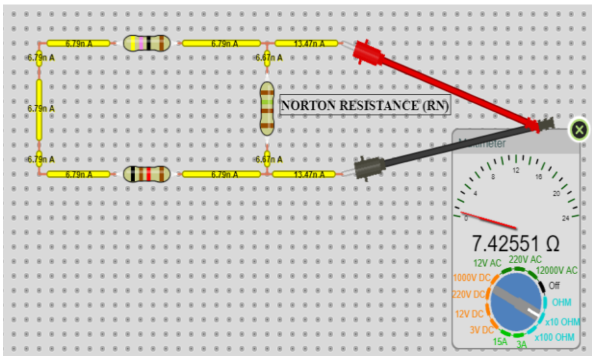
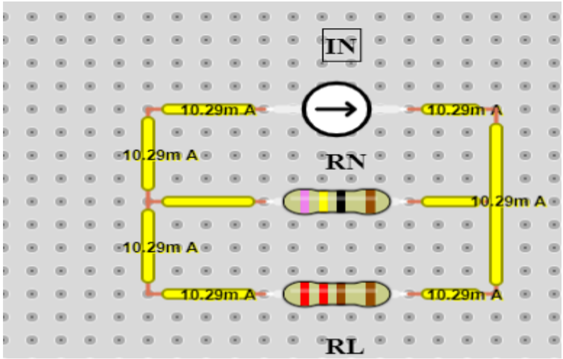


Figure 7: Evaluate of RN.

Once the values of IN and RN have been determined. Figure 8 shows the equivalent circuit of the Norton Theorem, which is built using the connection between RN and RL in parallel and IN as the supply source. The measurement of IL can be derived from this circuit.

Figure 8: Norton Theorem Equivalent circuit



C. Evaluation of Results (Theoretical and Experimental)

Students will now compare the results of the simulations with the calculations, and then they will do the hands-on work in the practical classes. By carefully following the steps outlined in the simulation, students will have no trouble conducting and building the circuit during the practical sessions.

V. RESULT AND DISCUSSION

A. Theoretical solution

By referring to Figure 4, remove the RL from the circuit. Figure 9 refers to the circuit after removing RL and based on the circuit the is calculated. The current flowing through a branch in a network is equivalent to the current flowing through the branch if it were directly connected to an electrical power source. Similarly, the internal impedance of the branch is equal to the impedance that would be seen across its open-circuited terminals, and the short-circuit current is equal to the current that would flow in a short-circuit across the branch. [15].

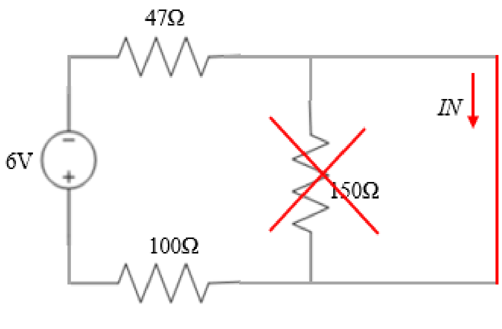


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Figure 9: Circuit without RL

Determine the Norton current (IN) using the Ohm law as a starting point for figuring out the circuit's total resistor value. The 150Ω resistor will be neglected as the current will bypass it. The occurrence is due to the resistor being in parallel with the short circuit. Equation 1 below shows the calculation of IN.

$$IN = \frac{V}{R} = \frac{6}{47+100} = 40.81mA. \ldots \textbf{Equations 2}$$

After the value of IN is calculated, according to Figure 10, remove all the voltage sources and short all the terminals to calculate the RN Norton's Theorem, similar to Thévenin's Theorem, is used to improve complex networks. The theorem enables the representation of a complex circuit, consisting of multiple energy sources and resistors, with a simplified model comprising a single current source and a parallel resistor. Thevenin's Theorem and Norton's Theorem are two related ideas frequently encountered in the field of electrical engineering. Duality arises when there is a consistent association between two variables. Here, voltage and current are considered duals. The dual of the Thevenin Equivalent Model is the Norton Equivalent Model. The Thevenin Equivalence Circuit (TEC) and the Norton Equivalence Circuit (NEC) are electrically equivalent. [16].

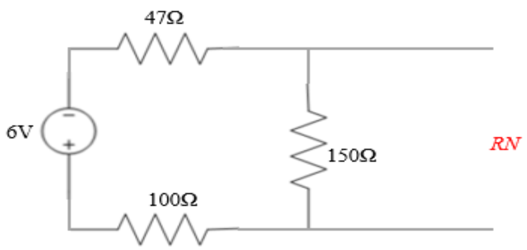

Figure 10: Circuit to calculate RN

Based on Figure 11, the value of IL can be determined by using the formula of Kirchoff's current law which according to Kirchhoff's Current Law (KCL), the sum of the currents entering a junction in an electric circuit is equal to the sum of the currents exiting the junction [17]. When a voltage is applied across a set of series resistors, the voltage across each individual resistor is divided in direct proportion to the resistance value of that resistor. The voltage divider rule, which can be derived from Kirchhoff's Voltage Law (KVL), describes this relationship. In a system of parallel resistors with a current passing through them, the current flowing through each resistor is divided in inverse proportion to the resistance value of each resistor. This relationship is defined as the current divider rule, and it can be derived from KCL. [18].

So, based on the calculation, the value of IL is equal to 10.29mA.

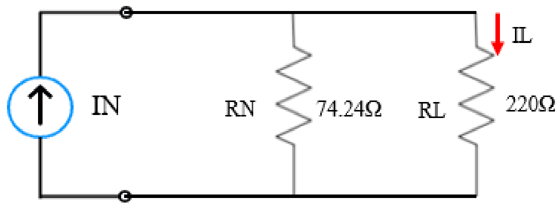

Figure 11: Equivalent circuit of Norton Theorem

$$IL = I_N \times \left(\frac{R_N}{R_N + R_L}\right)$$

$$= 40.81mA \times \frac{74.24}{74.24+220} = 10.29mA$$

A. Comparison between calculation and simulation results.

Table 1 shows the comparison result between the calculation and simulation of the Thevenin Theorem Circuit. Both results show the same answer. The current flowing through the circuit can be measured using an ammeter. It is standard practice to connect the ammeter in series with the circuit being tested. The low internal resistance of this metre does not affect the precise readings. [19]. The independent mode differs from the conventional experimental mode in a few important ways, including its innovative structure, interesting subject matter, and robust narrative coherence. There are three distinct facets to the subject at hand [20]:

i. The experiment's subject matter is the standard classic circuit theorem, which has given way to experimental design rather than experimental verification in the past. Because of this modification, the verification experiment is now more challenging than before.
ii. In this lesson, students learn the fundamentals of experimentation, how to use various instruments, and, when necessary, how to create their experimental circuits. The parameters and structure of the circuit are self-regulating. Students' intrinsic motivation to learn and excitement for experimentation are both boosted by this method, and they also demonstrate improved fundamental error detection and correction abilities, stronger experimental foundations, a deeper grasp of theoretical concepts, and the ability to apply what

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they've learned in the classroom to real-world circuit design. By conducting comprehensive and independent experiments, it lays a solid experimental groundwork for future design.

iii. No two levels are the same. The sophisticated experimental content design meets the needs of a wide range of educational goals. Make the most of each student's strengths while teaching them.

iv.

Table 1: Result between calculation and simulation

No	Calculation	Simulation
IN	40.81mA	40.76mA
RN	74.24Ω	74.26Ω
IL	10.29mA	10.29mA

VI. CONCLUSION

The purpose of this study was to compare the theoretical and practical outcomes for a direct current resistive circuit using a resistance range of 47Ω to 220Ω. The results presented the measured and computed values for the Norton Current, resistance, and load current. The Norton current and resistance values obtained from theoretical calculations align closely with the values measured experimentally, indicating a strong level of consistency. Besides that, based on the teaching methods, students can enjoy their learning and relate the theoretical part to simulation and practice.

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